The Present Status of the Control of Air-borne Infections*

FOR several decades prior to 1934 it was generally believed that the acute respiratory and contagious diseases were spread largely by contact.[1, 2] Since that time, however, it has been clearly established that the air of enclosed spaces may become heavily contaminated with a variety of pathogenic microörganisms, and that certain specific infections may be transmitted to experimental animals by the aerial route.[3–11] These observations have led many students to question the predominant rôle of contact in the spread of infection and to undertake investigations in the attempt to control disease by the application of engineering methods to the disinfection of air (sanitary ventilation) and to the prevention of aerial contamination (dust suppression).[12–17]

Numerous reviews of the subject have been published in scientific journals,[18–25] and optimistic but frequently uncritical stories of the potentialities of the field have reached the commercial and lay press. The purpose of this report is not primarily to present an additional review of recent progress but rather to give a critical evaluation of the present status and limitations of existing methods. Such an evaluation depends not only upon the engineering aspects of air sanitation but also on the epidemiological evidence supporting the concept of air-borne infection.

DEFINITION OF TERMS

Some confusion has arisen in the discussion of the subject because of the lack of a clear definition of terms. In the present report, the term *sanitary ventilation* will be used to connote the disinfection of air by actual ventilation or its equivalent through such methods as ultra-violet irradiation or germicidal vapors. The term *air sanitation* will include all types of applications of engineering methods to the prevention and removal of air contaminants such as dust, bacteria, and other noxious agents.

There is need also for a clarification of the term "air-borne infection." This expression has been applied to a number of respiratory and contagious diseases and to secondary skin and wound infections which are known to be spread, at least in part, by contact. A practical delineation of meaning of the terms "contact" and "air-borne" is desirable.

The routes by which these types of infectious agents travel from one individual to another may be classified under four general headings:

1. *Contact,* transmission directly, as in kissing, or indirectly by contaminated hands, toys, surgical instruments, or other material objects.
2. *Droplets,* transmission directly by projection onto the conjunctivae, mouth, skin, or open wounds.
3. *Droplet nuclei,* transmission indirectly by inhalation of the small residues which result from evaporation of droplets, and which may remain suspended in the air of enclosed spaces for long periods of time.
4. *Dust,* transmission indirectly by inhalation or settling of larger particles

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which arise from secondary reservoirs of infection on floors, clothes, or bedding, and which remain suspended in air for short periods of time.

The spread of infection by contact or by droplets is subject to control by methods which influence human behavior or restrict individual activity, such as the promotion of personal hygiene, isolation, quarantine, aseptic techniques, and barrier nursing. The spread of infection by droplet nuclei and dust is an environmental problem amenable to attack by methods of air sanitation.

Confusion arises in regard to the rôle which should be ascribed to droplets. Although these actually travel short distances through the air, it has been traditional to consider them as an intrinsic aspect of contact infection.[1] Furthermore, droplets are not affected appreciably by any of the devices of sanitary ventilation which have yet been developed. In the present discussion, therefore, the term "contact" will be considered to include droplets, and the term "air-borne" will be restricted to transmission of infection by droplet nuclei and dust.

GENERAL CONSIDERATIONS

On the basis of this definition, the technical aspects of the problem will be limited to an evaluation of the present status of the devices of air sanitation. Broader aspects of the problem must also be considered. It is necessary to know the true relative importance of air-borne and contact spread of disease under a wide variety of environmental conditions. The disinfection of air can be of practical value only in situations where the aerial route of infection is important in the mode of transmission.

Other considerations beyond the scope of the present report cannot be wholly ignored. The methods of air sanitation are in competition with other control measures. Aseptic techniques and isolation precautions are well established procedures in operating rooms and hospital wards. Immunization has been highly successful in certain specific diseases. Chemoprophylaxis may have limited applications. Therapy with sulfonamide drugs and antibiotics reduces in large measure the serious consequences of many bacterial infections. The future of air sanitation in the prevention of disease depends upon the demonstration of its practical superiority to other approaches to the problem.

PRESENT STATUS OF CONTROL METHODS

The methods of controlling air-borne infection have developed in four principal directions: (1) mechanical ventilation, (2) ultra-violet irradiation, (3) disinfectant vapors, and (4) dust suppression. In developing these procedures, the usual criteria of effectiveness have been the reduction: (1) of test organisms added to air, (2) of the total bacterial count of air, (3) of certain microörganisms usually found in the nasopharyngeal tract, and (4) of certain specific pathogens such as beta hemolytic streptococci or influenza virus A. While bacteriological criteria have been of great practical value in the development of the procedures, they are insufficient. The final criterion of effectiveness must be the demonstration of a significant reduction in the incidence of disease in well controlled studies in human populations living under natural conditions.

Ventilation — Simple ventilation by means of open windows has been a common hygienic practice for many years. Its use has been traditional in military barracks where it has been notable for its unpopularity among troops and the difficulty of its consistent enforcement. British workers have recently reëmphasized the desirability of open window ventilation in contagious disease wards.[26] Although it is probable that such measures may have considerable effect in reducing the bacterial contamination of the air, they are obviously expedients of limited value which are subject to variable climatic conditions and which may cause extreme discomfort.

Under certain specialized conditions, the control of air currents and air conditioning either alone or in conjunction with physical barriers and other procedures has been applied with somewhat variable success to the control of cross-infections in surgical dressing rooms,[27] in pediatric and premature infant wards,[15, 28–31] and in animal colonies and laboratories of research institutions.[32, 33] Under more general conditions, however, the purification of air through washing, filtration, and forced ventilation is a relatively inefficient method of reducing the bacterial content of air in occupied spaces.[34] Normal human activity maintains a continuous source of contamination which is difficult to eliminate by economical rates of air dilution. Nevertheless, a careful consideration of temperature, relative humidity, air currents, and rates of introduction of outside or recirculated air is fundamental to the effective application of the other more efficient means of air disinfection.

Ultra-violet irradiation—The bactericidal action of ultra-violet light is well established and accurately defined.[24, 35–40] The effectiveness decreases rapidly with increasing relative humidities above 55 or 60 per cent. The rays are more efficient against small particles, such as droplet nuclei, than large particles, such as dust and lint, in which microörganisms may have a protective coating impermeable to the bactericidal rays. Since germicidal intensities are damaging to the human skin and conjunctivae, radiation must be restricted to the upper air or to carefully placed light screens or barriers at the entrance to rooms or to isolation cubicles.[41] Under standardized test conditions practical intensities of ultra-violet light have been shown to have a marked effect in lowering the bacterial contamination of the air equivalent to 100 or more air changes an hour.[42] Under field conditions, this degree of effectiveness is not always reached; but, nevertheless, a pronounced effect may be induced.

The development of the low pressure mercury vapor tube, of carefully designed fixtures, and of accurate photometers to measure intensity makes possible the safe and reasonably economical installation of ultra-violet lights in a variety of circumstances. Each particular environmental situation, however, presents a specialized problem which requires the expert consultation and continued supervision of ventilation and irradiation engineers.[24]

The use of ultra-violet irradiation in the control of infection has been undertaken in operating rooms, in pediatric and contagious disease wards, in schools, in military barracks, and in children's institutions. The most impressive results have been reported from operating rooms.[14, 43] The residual contamination of the air which remains even after the most rigid aseptic precautions can be greatly reduced by intensive irradiation. Reports indicate substantial reductions in the incidence of secondary infections of originally clean operative wounds. To achieve such results, with early installations it appeared to be necessary to take extreme precautions to protect the operating personnel; but improved designs have made such precautions unnecessary.[43]

Ultra-violet irradiation of the upper air and the use of light screens in front of cubicles and in entryways to pediatric and contagious disease wards have been employed in a number of institutions. Rather dramatic results have been reported by a number of workers in carefully controlled experiments.[15, 31, 44]

Negative results have been reported by others.[45-47] It is difficult to evaluate these because of (1) inadequate information regarding the efficiency of the installations; (2) the lack of a sufficient number of controlled observations; and (3) the problem of distinguishing which infections were air-borne and which may have resulted from contact.

Irradiation of the upper air of schoolrooms in Swarthmore and Germantown, Pa., has been carried out continuously since 1937.[13, 48, 49] During the early part of this period, two epidemics of measles were apparently prevented among children in the primary grades whose rooms were irradiated, although large epidemics occurred among the less susceptible children in the secondary grades whose rooms were not irradiated. Beneficial effects in the reduction of the incidence of chicken pox have also been reported, although the procedure was less successful in controlling an epidemic of mumps which occurred in the early fall of 1941 when relative humidities were high.

The application of ultra-violet rays in the schoolrooms provides a very valuable approach to studying the importance of air-borne spread of infection, but the extent to which this procedure should be applied generally is uncertain. More extensive studies, now in progress, should add materially to our understanding of the problem.

Irradiation of the upper air, of the corridors, and of the floors of the naval barracks at Camp Sampson, New York, was investigated during the winter of 1943–1944.[50] In one group which received high intensity irradiation, there was a 25 per cent lower incidence of "respiratory admissions" than among comparable groups of controls. These studies have been continued and extended, but results have not yet been reported.

One study of ultra-violet irradiation has been conducted in the restricted population of an institution for delinquent adolescents in Washington, D.C.[51] No reduction in the incidence of respiratory disease was demonstrable over a period of two years, but the total incidence rates were generally so low that a measurable effect could hardly have been anticipated.

These studies suggest that ultraviolet irradiation has its most direct application in specialized situations where the incidence of cross-infection is high, where the consequences of such infections are serious, and where the population is strictly regimented, as in operating rooms, pediatric hospitals, and analogous situations. However, the evidence, at present available, is insufficient to warrant the use of ultra-violet lights in more general population groups except in well controlled research studies.

Disinfectant vapors—Numerous vapors have been shown under experimental conditions to have a powerful bactericidal effect in air. Among these are hypochlorous acid gas,[52] lactic acid,[53] iodine,[54] and certain glycols.[16, 21, 55, 56] Triethylene glycol appears to be the most adaptable for general use because of its high bactericidal potency, its reasonable cost, and its freedom from odors, toxicity, and corrosiveness to metal surfaces. The mechanism of action of this vapor has been carefully studied.[57] Its bactericidal effect depends upon its relative saturation in the air rather than upon the total concentration. Under laboratory conditions the vapor is most effective at relative humidities between 30 and 55 per cent. On hospital wards, however, effective bactericidal action was obtained at relative humidities as low as 18 per cent.[58] Methods for vaporizing triethylene glycol into the air and for maintaining its relative saturation at a constant level have been developed on an experimental basis and give promise for being standardized for practical purposes.[57, 59]

Glycol vapors are more effective

against small particles or droplet nuclei in the atmosphere than they are against larger dust particles.[60] The most effective reduction in bacterial contamination has been observed when glycol vapors have been used in conjunction with dust suppressive measures.[61]

Studies of the effect of glycol vapors in the control of respiratory infections have been conducted in isolation wards of army hospitals,[61, 62] in barracks,[63, 64] and in a home for crippled children.[65] Most of these studies, however, were undertaken prior to the development of accurately standardized methods for maintaining the concentration of vapors at a bactericidal level. Observations have not been continued for sufficient periods nor have controls been adequate to provide conclusive evidence.

The use of glycols has one distinct advantage over ultra-violet irradiation in that the vapor may permeate all parts of the room and is not restricted to the upper air. There are, however, a number of technical problems which remain to be solved, among which are practical methods of vaporization and maintenance of an adequate and even distribution of bactericidal concentrations of vapor.[66]

Dust suppression—The application of light paraffin or spindle oil to the floors of military barracks and army hospital wards has been shown to be a simple and effective procedure for laying dust and thereby reducing the bacterial contamination of the air resulting from sweeping or other activity.[67] A saturation dose of oil to unvarnished soft wood floors remains effective for a period of three months or longer. More frequent treatments may be necessary for hardwood floors. The procedure cannot be used for concrete, linoleum, or waxed surfaces, but the daily use of oiled sawdust or oiled mops during sweeping is quite effective.

Numerous methods have been developed for the oil impregnation of blankets, bedding, and certain types of clothing.[68–73] Treated fabrics show marked dust and bacteria holding properties. Recently, a simple method has been developed which can be applied as a routine procedure in any modern well equipped laundry.[72] A stable oil in water emulsion, made with a neutral detergent, Triton N.E., is added at the time of the final rinse in the laundering process. After such treatment, woollen fabrics such as blankets retain their dust and bacteria holding properties for many months, even after subsequent washing.

A few controlled studies of the effect of dust suppressive measures on the incidence of respiratory disease have been carried out. A marked reduction in the incidence of beta hemolytic streptococcal cross-infections was observed in one measles ward compared with an untreated adjacent ward to which alternate cases were admitted.[17] At Fort Bragg, N. C., during the winter of 1944–1945, four battalions of recruits (2,000–4,000 men) were observed over a period of 6 months.[74] In the barracks of alternate batteries floors and blankets, sheets, pillow cases, and mattress covers were oil-treated. During November and December when respiratory diseases were endemic, somewhat lower rates were observed in the treated groups. During the 4 month period from January to April, however, when undifferentiated acute respiratory disease was epidemic, no difference in incidence between test and control groups was observed. In this experiment the incidence of beta hemolytic streptococcal infections was too low to test the effect of the procedures on this group of diseases.

The oiling of floors and bedding has been developed to the stage of practical application. These methods are particularly useful for the maintenance of general cleanliness; they result in a marked reduction in the degree of bacterial contamination of the air; they can be recommended for use as general hygienic measures; but there is insufficient evidence at the present time to establish their value in the control of respiratory diseases.

EPIDEMIOLOGICAL CONSIDERATIONS

The limiting factor in the evaluation of the effectiveness of measures to control air-borne infection is the lack of sufficiently extensive experimental and epidemiological observations to determine the true relative importance of this mode of spread. The available data can be grouped under three broad headings: (1) Experimental demonstrations of air-borne infection, (2) descriptive field observations, and (3) controlled studies. Each of these will be discussed briefly.

Experimental demonstrations—A limited number of infections have been transmitted to animals and to man by the air-borne route under strictly controlled conditions. Examples of these experiments are the transmission of tuberculosis to rabbits,[11] of influenza A and B to mice and ferrets,[4, 75-77] of canine distemper to ferrets and dogs,[78] and of poliomyelitis to monkeys.[79] During the direct inoculation of volunteers with the viruses of measles[80] and atypical pneumonia,[81] cross-infections were observed among uninoculated individuals under conditions which strongly suggested the air-borne route of infection. These observations clearly demonstrate that certain infectious agents may be acquired by inhalation in sufficient doses to produce clinical disease.

Descriptive field observations — In most epidemics of respiratory and contagious diseases which occur in nature, it is not possible to distinguish between contact, droplets, and air-borne methods of transmission. In certain laboratory epidemics, however, conditions have precluded any other means of spread than the air. This is particularly true for psittacosis[82] and Q fever,[83, 84] and it also probably applies to a number of bacterial, rickettsial, and viral infections which are known to be peculiarly dangerous to laboratory workers or which are difficult to exclude from animal colonies.

The occurrence of cross-infections in communicable disease wards and of secondary infections in clean surgical wounds was formerly considered to be *a priori* evidence of faulty technique. The consistency with which a residual number of such infections have continued to occur, however, in spite of the most rigid precautions favors the concept of air-borne spread.[22] The demonstration of large secondary reservoirs of beta hemolytic streptococci, of diphtheria bacilli, of staphylococci and other pus forming organisms in the environment, and in the dust surrounding patients also supports strongly the possibility of air-borne transmission. It should be emphasized, however, that under such conditions the likelihood of contact infection is also greatly increased, and it is difficult to ascertain the relative importance of these two modes of spread.

Controlled studies—As yet, an insufficient number of adequately controlled studies have been reported upon which to base any general conclusions. Only certain tentative indications may be outlined at the present time. For example, the reduction in the incidence of operative wound infections and of cross-infections in pediatric and communicable disease wards and of measles in certain schools by the use of ultra-violet irradiation suggests that air-borne transmission, particularly by droplet nuclei, played an important rôle under the particular conditions of those experiments. Similarly it is reasonable to conclude that droplet nuclei were of some importance in the transmission of acute respiratory diseases in the naval barracks at Camp Sampson. On the other hand, an equally logical conclusion can be drawn from the studies at Fort Bragg that dust was an unimportant factor in the spread of the epidemic acute respiratory disease prevalent at that post. Furthermore, the spectacular results which followed the introduction of aseptic surgery and isolation techniques thirty to fifty years ago indicate the importance of contact infection in operating rooms and hospital wards.

Conclusive evidence is not available at present that the air-borne mode of transmission of infection is predominant for any particular disease. There is no justification for the conclusion that the traditional methods of controlling contact infection can be ignored or relaxed.

There is need for more precise knowledge regarding the epidemiology of acute infectious diseases in crowded populations. For example, recruits in military training camps generally experience an unusually high incidence of acute respiratory disease and atypical pneumonia during winter months.[85] During the war years, devastating epidemics of beta hemolytic streptococcal infections and acute rheumatic fever occurred in certain camps.[86–89] The value of air sanitation for controlling these epidemics depends upon the extent to which the infections may be air-borne. The conduct of controlled studies using various techniques of disinfecting air and suppressing dust is one of the few means of answering this question.

CONCLUSIONS

The subcommittee offers the following five points to summarize its group judgment concerning the present status of the application of engineering methods to control air-borne infection:

1. The oiling of floors, blankets, and bedding has now developed to the point of practical application in the suppression of dust. Such measures constitute good housekeeping. They reduce bacterial contamination of the air, but there is as yet insufficient evidence that they prevent disease. Dust suppression should be applied wherever practicable in conjunction with ventilation, ultra-violet irradiation, and disinfectant vapors, when the latter methods are employed.

2. The available evidence strongly indicates that methods of air disinfection (ventilation, ultra-violet irradiation, and glycol vapors) are useful adjuvants to aseptic techniques in the reduction or elimination of air-borne infections in operating rooms and in contagious disease and pediatric wards. Installations are indicated under conditions where there has been demonstrated or there exists potentially a significant incidence of cross-infection or a serious risk to patients. It is essential that competent engineering supervision be available to insure the adequacy of the original installation, to maintain its continued effectiveness, and to protect both personnel and patients.

3. It is not yet possible to compare the relative efficiency of ultra-violet irradiation and glycol vapors. Only the former method has been developed to a point of practical application. Recent designs of glycol vaporizers and automatic control devices give promise that adequately controlled studies may be conducted in the near future. The relative merits of the two procedures will involve such problems as cost, safety, and the consistency of effective operation based upon long experience.

4. The general use of ultra-violet irradiation or disinfectant vapors in schools, barracks, and in specialized industrial environments is not justified at the present time. There is great need for further carefully controlled field studies to define the mechanisms of the spread of infectious disease among these types of populations.

5. There is no justification for the indiscriminate use of ultra-violet light or other methods for disinfecting air in homes, offices, or places of public congregation.

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